TREATMENT OF DAIRY WASTEWATER BY ELECTRO-COAGULATION PROCESS: EFFECT OF VARIOUS PARAMETERS

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Abstract— **Industrial dairy effluents constitute high biological oxygen demand (BOD) and chemical oxygen demand (COD) concentrations and contain nutrients, fats, lactose, as well as detergents and sanitizing agents. In the present study, the treatment of simulated dairy wastewater(SDW) by electrocoagulation(EC) technology has been examined using aluminum electrodes. Experiments were conducted in a laboratory-scale batch EC reactor. The effects of various parameters such as initial COD, conductivity, current density, and pH have been evaluated on COD removal, anode consumption, and specific electrical energy consumption(SEEC). Maximum COD removal of 77.81% was obtained at 2.40 mA/cm^2 in 30 minutes electrolysis time. For current density in the range of 1.92-2.88 mA/cm^2, anode consumption was reported in the range of 0.052-0.150 mg/mg COD removed, while SEEC was reported in the range 0.075-0.270 J/mg COD removed. The effluent pH after EC lied between 8.29-8.64 depending on the initial pH. Thus, EC technology with aluminum electrodes is an attractive choice for environmentally sound and cost-effective treatment of industrial dairy effluents.**

Index Terms— Electrocoagulation, Aluminum electrodes, COD, Dairy effluent.

I. INTRODUCTION

Speedy growth in the requirement for milk and milk-related products has led to research and developments in the veterinary industry, due to which a steady growth in the production of cattle milk has been observed [1]. Due to this, there has been a massive growth of dairy industries in most countries of the world including India. India not only ranks first in milk production but also is the world's largest consumer of milk[2]. As a result, the quantity of dairy wastewater generated and discharged from milk-processing industries has also increased.

Dairy wastewaters constitute high biological oxygen demand (BOD) and chemical oxygen demand (COD) concentrations and contain nutrients, fats, lactose, as well as detergents and sanitizing agents [3]. The dairy industries discharge untreated/partially treated wastewater due to the high pollutant concentration of dairy wastewater which causes serious environmental problems [4] such as the exhaustion of the dissolved oxygen concentration, increase in the microbial biomass, deposits of mud, mushroom and algae proliferation and eutrophication of receiving surface waters such as rivers, lakes, ponds, etc [5].

In the current study, the electrocoagulation method has been used to treat simulated dairy wastewater. EC method implies sacrificial anode, in which when the electric current is applied the metal cations of coagulation are released in situ.

Simultaneously, the electrolytic reactions generate oxygen bubbles to the anode and hydrogen bubbles to the cathode, which favors the floatation of the particles [5]. The effects of different parameters such as initial COD, conductivity, current density, and pH have been evaluated on COD removal, anode consumption, and specific electrical energy consumption(SEEC).

II. MATERIALS AND METHODS

A. EC Apparatus

Batch experiments were performed using a reactor with an effective volume of 2L. Electrodes were connected in the mono-polar mode. Two aluminum electrodes of dimensions: 10cm width, 7.8cm height, 0.3cm thickness; with a purity of 98.99% and surface area of 155 cm^2 were used. For all the experiments, the electrode gap was kept as 2 cm. Electrodes were connected to a DC power supply (Testronix, 0-30V, 0-5A) in the monopolar configuration. A magnetic stirrer was used at 50 rpm to stir the solution to obtain a homogeneous wastewater-flocs mix. The laboratory-scale batch EC setup with a monopolar electrode connection is shown in Figure 1. No exact reactor design configuration has been suggested in the literature. However, the ratio of the surface area of the electrode(S) to the volume of the reactor(V) is available. In the present work, S/V ratio is kept as 7.8m^2/m^3 which is within the cited range in the literature [6].

Fig.1. Diagram of the experimental setup.

B. Experimental Procedure

Non-natural dairy effluents were prepared by dissolving 1g ready-made milk powder per liter of tap water. The characteristics of the wastewater used are presented in Table 1. In the aluminum electrodes, the passivation layer is developed that provides resistance which increases energy consumption but does not increase coagulant or bubble production rates. Also, it thwarts the effective current movement between the anode and cathode [7]. Therefore, to eliminate any passivating material, electrodes were dipped in HCl (35%)for 10 minutes. This was followed by a distilled water wash to remove impurities from the electrode surface and oven-dried. After oven drying, the electrodes were scrapped with sandpaper before EC experiments. pH was adjusted using 0.1N H_2SO_4 and 0.1N $NaOH$ solutions to a desirable value before the commencement of the experiments. Wastewater conductivity was also adjusted to a range between 1000µs/cm-2000µS/cm by adding a suitable amount of $NaCl$. All the samples were filtered with a WHATMAN 1.2 µm filter paper.

TABLE I: The Arrangement of Channels

Characteristics	Value
Chemical oxygen demand(COD)(mg/L)	1300±50
Biochemical oxygen demand(BOD) (mg/L)	950±60
Total solids(mg/L)	1791±150
Total dissolved solids(mg/L)	1062±140
Total suspended solids(mg/L)	729±10
Turbidity(NTU)	470±10
pH	7.60±0.20
Conductivity(µS/cm)	750±10

The % COD removal, anode consumption, and SEEC were computed using the following relationships:

$$\% \ COD \ removal = \frac{(C_0 - C_f) * 100}{C_i}$$

where C_o and C_f are the initial and final COD concentrations (mg/l) after T (min).

$$Anode \ consumption = \frac{I * T * M}{f * Z * F * V * C_0 * \frac{Y_T}{100}}$$

where I is the current in ampere, T is time in sec, M is the molecular mass of Al (27 g/mol), Z is valency number (Z=3 for aluminum), f is the ratio of electrochemical dissolution, V is the volume of the solution (L), F is Faraday's constant (96485C/mol), Y_T is removal efficiency at time T(%).

$$SEEC(J/mg) = \frac{(I.\int_0^T U.dT)}{V.C_0.\frac{Y_T}{100}}$$

where U is the voltage and T is time in minutes.

III. RESULTS AND DISCUSSION

A. Effect of current density

Current is the most susceptible parameter as it can influence the efficiency of EC treatment. It determines the amount of coagulant and the rate and the size of the bubbles generated at the electrodes [5]. Current density and electrolysis time are inter-dependent. If the current density is less, electrolysis time will be more for COD/BOD removal and vice versa. The electrolysis time was kept constant at 45 minutes and the current was varied from 0.5A to 0.9A. The inter-electrode distance was kept at 2 cm. Conductivity was kept at 1500 µS/cm, and pH was adjusted to 7. Samples were collected every 5 minutes and COD removal was observed. The results are presented in Figure 2. From Figure 2, it can be observed that %COD removal is low at 1.60 mA/cm². Maximum COD removal of 77.81% was obtained at 2.40 mA/cm² in 30 minutes electrolysis time. %COD removal decreases at and above 2.56 mA/cm². Thus, the investigational results showed that at higher current densities, more coagulant (aluminum) is available per unit time, which is unnecessary, as it reduces COD removal, is uneconomical in terms of energy consumption and excess residual aluminum has the neuro-toxic effect. Electrolysis time is a vital parameter in the EC process. From Figure 2, it can be observed that for a fixed current density, COD removal efficiency enhances with an increase in electrolysis time. Up to 55-65% COD removal occurs in the initial 15 minutes. As time progresses, the

increase in COD removal keeps decreasing. This is because the availability of the pollutant in the solution becomes a limiting factor. From Figure 2, it can be observed that at lower current density i.e. 1.60 mA/cm^2, optimum COD removal of 64.90% is obtained at electrolysis time of 35 minutes, while at higher current densities of more than 2.56 mA/cm^2, optimum COD removal is achieved in electrolysis time of 25 minutes.

Electrolysis time, Current density, and conductivity determine the quantity of aluminum dissolved in the solution. Increasing the electrolysis time and the current density increases the anode dissolution which increases the COD removal. From Figure 3, it is established that with the increasing current density, coagulant matter (aluminum hydroxide) was consumed more ineffectually and become less fruitful. This is because the rate of release of hydrogen gas from cathode increases despite the increase in the quantity of aluminum given to the medium and flocking feeding rate. With the increase in the number of hydrogen bubbles, they stick to the crystals of coagulant more which causes these crystals to float on the surface of the reactor more quickly (floatation effect) [8]. When the current density is in the range of 2.24-2.4 mA/cm^2, COD removal increases more than the increase in anode consumption, and their ratio almost becomes constant. Thus, coagulant matter was used more efficiently here compared to other range of current densities. COD removal starts decreasing as shown in Figure 3 beyond the current density of 2.4 mA/cm^2 while the anode consumption keeps increasing. Thus, their ratio decreases. Anode consumption was reported in the range of 0.052-0.150 mg/mg COD removed for the current density of 1.92-2.88 mA/cm^2.
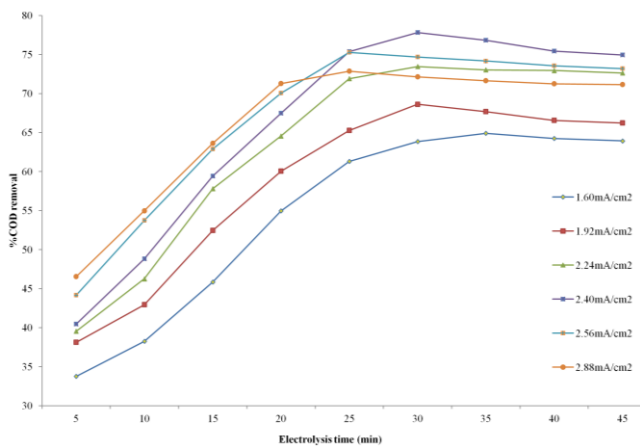
SEEC is affected by the applied voltage, current, electrolysis time, and conductivity. Increasing the conductivity will result in a decrease in SEEC. This is due to a reduction in the cell voltage with an increase in the conductivity of the solution at constant current density. SEEC was reported in the range 0.075-0.270 J/mg COD removed for current density in the range of 1.92-2.88 mA/cm^2. From Figure 4, it can be observed that there is a wastage of electrical energy beyond the current density of 2.4 mA/cm^2 as the residual COD starts increasing.

When the current density is 1.60 mA/cm^2, COD removal of 54.97% is achieved in 20 minutes electrolysis time with energy consumption of 0.042 J/mg COD removed, while the similar COD removal of 54.98% is achieved in only 10 minutes when the current density is 2.88 mA/cm^2 with energy consumption of 0.076 J/mg COD removed. Thus, the critical process parameters should be found out because the volume of the reactor to be used needs to be increased at lower current density. However, aluminum can be used more effectively as shown in Figure 3, and the energy consumption of the system also decreases. Also, when higher current densities are applied, reaction time shortens and the energy consumption increases[8].
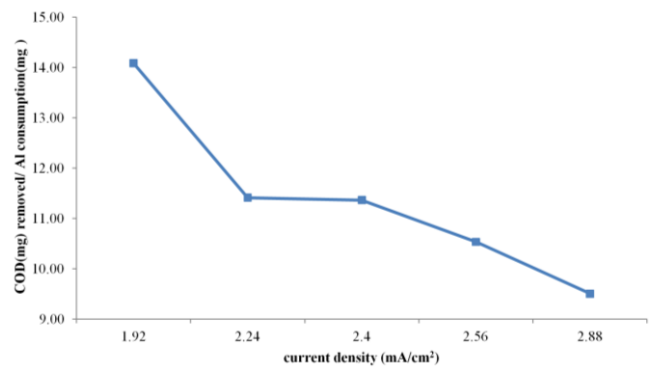

Fig.3. The change of COD(mg) removed per aluminum amount(mg) as a function current density (pH=7, conductivity=1500μS/cm).
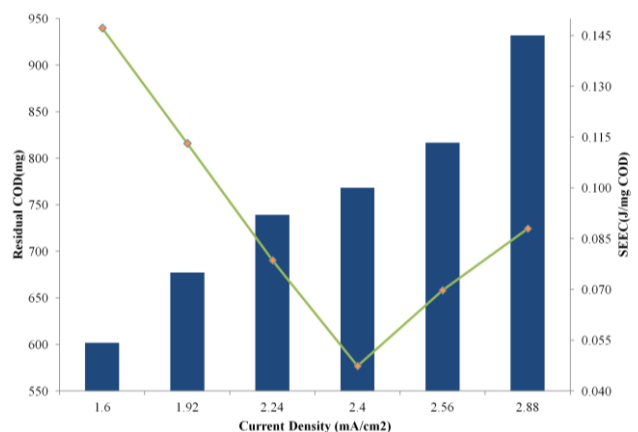

Fig.2. Variation of % COD removal with electrolysis time at different current densities (pH=7,conductivity=1500 μS/cm).

Fig.4. Effect of current density on SEEC and residual COD (pH=7, conductivity= 1500 μS/cm).

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B. Effect of pH

Al^{3+} and OH^- ions produced by the electrodes when the pH is between 4 and 9 react to form various monomeric species which are transformed finally into amorphous insoluble compounds $Al(OH)_3$ by polymerization kinetic complexes/ precipitation. The formed precipitate increases solubility when the solution becomes very basic[5]. Between pH 6 and 8, the solid $Al(OH)_3$ is most prevalent. Above pH 9, the soluble species $Al(OH)_4^-$ is the major species[7]. When the initial pH was between 6-8, effluent pH was above 8 within 10 minutes of electrolysis time. This is also evident from the fact that 55-65% COD removal occurs in the initial 15 minutes as discussed in the previous section. Anode consumption and SEEC are marginally affected in the pH range of 6-8. The effluent pH after EC lied between 8.29-8.64 depending on the initial pH.

C. Effect of conductivity

The conductivity of the simulated dairy wastewater was 740-750 µS/cm, which was low. Due to low conductivity, energy consumption was high, and COD removal was low. Thus, the conductivity was increased by adding *NaCl* because chloride ions can considerably reduce the poor effect of other anions such as HCO_3^-, SO_4^{2-}. The precipitation of Ca^{2+} or Mg^{2+} ions due to the presence of carbonate or sulphate ions forms an insulating layer on the surface of the electrodes. Due to this insulating layer, there is a sharp rise in the potential between electrodes and a major dip in the current efficiency. Therefore among the anions present, there should be 20% Cl^- ions to make sure a normal operation of the electro-coagulation process in water treatment. Power consumption also decreases when the NaCl is added due to the increase in Furthermore, the electrochemically produced chlorine was found to be valuable in water disinfection. From Figure 5, it can be observed that there is only a small increase in COD removal efficiency beyond 1500µS/cm. Also, increasing conductivity in the solution decreases the anode consumption as shown in Figure 6.
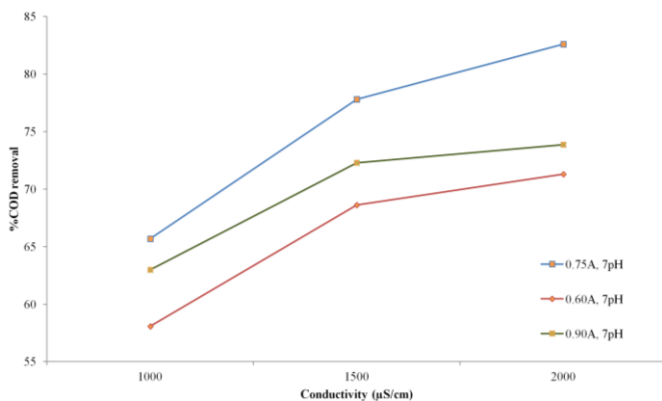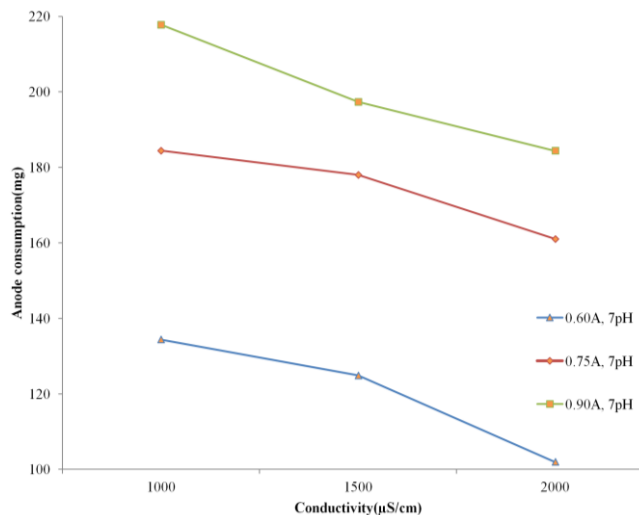

Fig.6. Variation of anode consumption with conductivity and current.

D. Effect of initial COD

As shown in Figure 7, when the initial COD concentration is increased from 900-1700 mg/L, COD removal increases from 76.43 to 81.12%. This is due to the presence of excess colloids for the adsorption in high concentrations of COD[10].
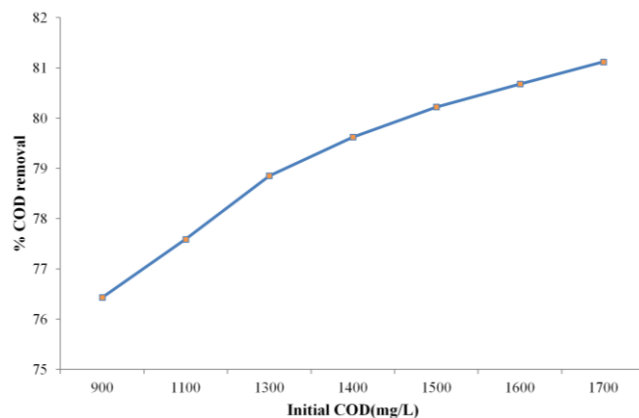

Fig.7. Variation of % COD removal with initial COD at different currents

IV. CONCLUSION

In the current study, the electrocoagulation method has been used for simulated dairy wastewater with initial COD of 1300 mg/L, which is in the range of industrial dairy wastewater. In this process, the electricity is passed through contaminants and pollutants by which chemical bonds are broken down. This technology is more efficient than simple chemical coagulation and filtration. Experimental investigations were carried out to remove COD/BOD of wastewater at low operating cost using aluminum electrodes. Up to 55-65% COD removal occurs in the initial 15 minutes of the EC process. %COD removal decreases at and above 2.56 mA/cm² for constant electrolysis time of 30 minutes. Increasing the electrolysis time and the current density increases the anode dissolution

Fig.5. Variation of % COD removal with conductivity at different currents.

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while increasing conductivity in the solution decreases the anode consumption. Anode consumption is in the range of 0.052-0.150 mg/mg COD removed. SEEC is affected by the applied voltage, current, electrolysis time, and conductivity. SEEC is in the range 0.075-0.270 J/mg COD removed.

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REFERENCES

[1] J.P. Kushwaha, V.C. Srivastava, and I.D. Mall, "An Overview of Various Technologies for the Treatment of Dairy Wastewaters," *Food Science and Nutrition,* Volume 51, pp. 442-452, 2011.

[2] Press Information Bureau, Ministry of Finance Government of India, 2016. [Online] Available at: https://pib.gov.in/PressReleseDetailm.aspx?PRID=1603507 [Accessed 17 July 2020].

[3] USDA-SCS, *Agricultural Waste Management Field Handbook.* Washington, DC: U.S. Department of Agriculture-Soil Conservation Service, 1992.

[4] B. Montuelle, J. Coillard and J.B. Lehy, "A combined anaerobic-aerobic process for the co-treatment of effluents from a piggery and a cheese factory," *Journal of Agricultural Engineering Research ,* Volume 51, pp. 91-100, 1992.

[5] A. Aitbara, M. Cherifi, S.Hazourli and J.P. Leclerc, "Continuous treatment of industrial dairy effluent by electrocoagulation using aluminum electrodes," *Desalination and water treatment,* doi: 10.1080/19443994.2014. 989 411,2014.

[6] N. Mameri, A. Yeddou, H. Lounici, D. Belhocine, H. Grib, B. Bariou, "Defluoridation of septentrional Sahara water of North Africa by electrocoagulation process using bipolar aluminum electrodes," *Water Research,* 32(5), pp. 1604-1612, 1998.

[7] V. Khandekar and A.K. Saroha, "Electrocoagulation for the treatment of textile industry effluent-A review," *Journal of Environmental Management,* Volume 128, pp. 949-963,2013.

[8] S. Bayar, Y.S. Yildiz, A.E. Yilmaz and S. Irdemez, "The effect of stirring speed and current density on removal efficiency of poultry slaughterhouse wastewater by electrocoagulation method," *Desalination,* 280(1-3), pp. 103-107, 2011.

[9] R. Sinha, I. Khazanchi and S.Mathur, "Fluoride Removal By A Continuous Flow Electrocoagulation Reactor From Groundwater Of Shivdaspura," *International Journal of Engineering Research and Applications,* 2(5), pp. 1336-1341, 2012.

[10] I.A. Sengil and M. Ozacar, "Treatment of dairy wastewaters by electrocoagulation using mild steel electrodes," *Journal of Hazardous Materials,* Volume 137, pp. 1197-1205, 2006.

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